# SOLUTION FOR THE PREVENTION OF LENS HAZING

Semiconductor Filtration

## BREAKTHROUGH CHEMICAL ANALYSIS OF HMDS REVEALS A SOLUTION FOR THE PREVENTION OF LENS HAZING

### DONALDSON PROVES THAT ADVANCED LAYERING TECHNOLOGY AND BSMMAX FILTERS EFFECTIVELY REMOVE TMS, $NH_3$ AND HMDSO

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## OBJECTIVE

To identify the most effective solution for lens hazing by gaining the industry's most in-depth understanding of the HMDS to TMS/HMDSO chemistry process in ambient air.

## CONCLUSION

It is necessary to focus on the hydrolysis products of HMDS to ensure adequate removal of volatile siloxane compounds. We have shown that the hydrolysis of HMDS predominantly creates TMS and ammonia, and layered adsorbents can effectively remove these compounds. Activated carbon or carbon impregnated with a base for the removal of acids are very effective at removing hydrocarbons and siloxanes such as TMS or HMDSO. Furthermore, acid impregnated carbons are effective at removing ammonia and also catalyzing the dimerization of TMS to the less volatile, and easily removed HMDSO.

In recent years as the industry has moved from 248 nm lithography tools to higher powered 193 nm tools, a new and costly problem emerged for semiconductor processors: molecular contamination on the optics (lens hazing). Because progress in one area almost always prompts new concerns in another, Donaldson has applied its more than 90 years of filtration expertise to learn more about this problem and discover the breakthrough solution. With so much at stake—costly lens replacement along with lost time and productivity—Donaldson's network of engineers delved into the problem to gain a clear understanding of the undefined chemistry issues involved with both ammonia and organics. While previous studies[1] have attempted to unlock the mystery behind lens hazing, this definitive Donaldson study is the first of its kind to reveal in-depth analysis of the adsorption of HMDS, HMDSO and TMS in semiconductor facilities. Through greater understanding of the chemistry involved, Donaldson creates superior processing environments with its advanced, cost-effective filtration solution: **BSMmax**.

## FOCUSING ON HMDS

Lens hazing is caused by salt deposition and by siloxane contamination, which causes severe and sometimes irreversible damage. To date, the concern in lens hazing has focused on siloxane contamination from hexamethyldisilazane (HDMS). HMDS is commonly used as a wafer treatment to improve adhesion of the photoresist on to the wafer, and the presence of HMDS has been linked to lens hazing in the 193 nm lithography tools.[2] Once the lens has become contaminated with haze it must be cleaned or removed and replaced. This type of repair requires the adjustment of the optical axis and involves extensive downtime. The detrimental

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effects of siloxane contamination are not limited to lenses on lithography tools, but also reticles and masks, inspection tools, and other critical surfaces. Small amounts of siloxanes normally found in indoor air are enough to cause problems, so siloxanes must be eliminated.

## CHALLENGES OF REMOVING AMMONIA AND SILOXANES

Historically, filtration in the lithography area has concentrated on ammonia removal via acid impregnated media or cation exchange resins. These methods, however, are not effective in removing siloxanes (organics) such as HMDS or HMDSO. Donaldson enlisted its industry leading expertise in organics removal to take a more critical look at this issue. Typically, adsorbents would be used to remove organic compounds like HMDS and HMDSO, however, ammonia is not removed without acid impregnation.

To better understand the most effective removal strategy, Donaldson worked collaboratively with our semiconductor customers who provided filter media for testing from their fabs after use. Donaldson studied the mechanism of reactions of HMDS in the air and on the filter media. The analysis showed that these fabs' filter media contain both TMS and HMDSO. However none of these filters were found to contain HMDS indicating the instability of HMDS in air and on the surfaces of these filter adsorbents.

## FILTRATION KNOWLEDGE REVEALS THE ANSWER

Donaldson conducted experiments using a typical breakthrough test bench design. The test bench consisted of an ultra-high purity air line controlled to a specific temperature, humidity, and flow rate. A contaminant vapor was added at a specific rate and diluted with the air stream to achieve the desired concentration. The contaminated air then passed through a media sample holder. A portion of the air stream was directed to an On-Line Technologies model 2010 Fourier transform infrared spectrophotometer (FTIR) for analysis.

The temperature and humidity in semiconductor manufacturing facilities is tightly controlled at about 25°C and 45% relative humidity. We added HMDS

## HOW HMDS CONVERTS TO TMS/HMDSO

Drawing on its filtration expertise and R&D resources, Donaldson set out to analyze HMDS by running it through an catalyst to generate TMS in the lab. HMDS has been shown to hydrolyze in solution to trimethylsilanol (TMS) plus ammonia as shown in **Equation 1**, or directly to hexamethyldisiloxane (HMDSO) and ammonia as shown in **Equation 2**.[3]

Through its lab tests and analysis, Donaldson subsequently discovered the new breakthrough that TMS undergoes acid catalyzed dimerization into HMDSO as shown in **Equation 3**.

In order to protect expensive optics, it is essential to effectively control not only HMDS, but equally importantly, its decomposition by-products—both ammonia and siloxanes (organics). As shown in equations 1-3, TMS, $NH_3$ and HMDSO can readily be found in the environment of these lens systems.

**EQUATION 1**

$$\underset{\text{HMDS}}{((CH_3)_3\,Si)_2\,NH + 2H_2O} \longrightarrow \underset{\text{TMS}}{2(CH_3)_3\,SiOH + NH_3}$$

**EQUATION 2**

$$\underset{\text{HMDS}}{((CH_3)_3\,Si)_2\,NH + H_2O} \longrightarrow \underset{\text{HMDSO}}{((CH_3)_3\,Si)_2\,O + NH_3}$$

**EQUATION 3**

$$\underset{\text{TMS}}{2(CH_3)_3\,SiOH} \xrightarrow{H+} \underset{\text{HMDSO}}{((CH_3)_3\,Si)_2\,O + H_2O}$$

vapor to an air stream in our test bench and found that under these conditions HMDS can hydrolyze in air to form TMS and ammonia as shown in **Figure 1**.

**Figure 2** shows the concentration of TMS, $NH_3$, and HMDSO down stream of a sample of filtration media when exposed to HMDS as described above. As expected, filtration media alone removes TMS very well, despite its volatility, and does little to remove ammonia.

Also as expected, **Figure 3** shows that acid impregnation alone removes ammonia very well, but does little to remove TMS. It also proves that HMDSO is generated through the acid catalyzed dimerization of TMS.

## THE LENS HAZING SOLUTION

Through testing and analysis, Donaldson proved that layering effectively removes ammonia, TMS and HMDSO. The benefits of this combined adsorbent system are evident in **Figure 4**. This shows the effective removal of $NH_3$, TMS, and HMDSO. These observations show that the optimized filtration solution, BSMmax filters with layering technology, is effective at removing the two primary culprits of lens hazing—ammonia and siloxanes.

▬ TMS ▬ Ammonia ▬ HMDSO ▬ HMDS

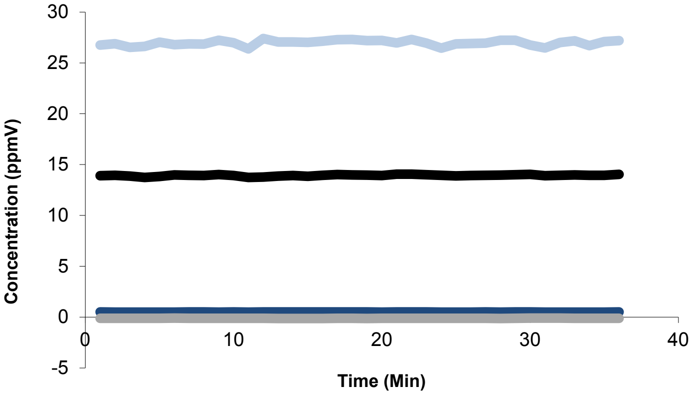

**FIGURE 1** – HMDS in air at 25°C and 50% relative humidity yields TMS and $NH_3$.

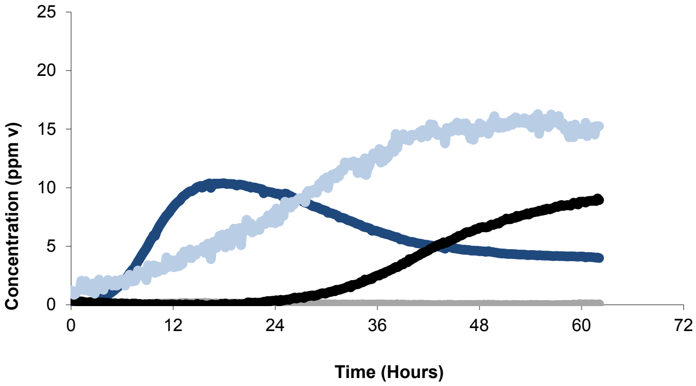

**FIGURE 2** – Ammonia control with single layer of media

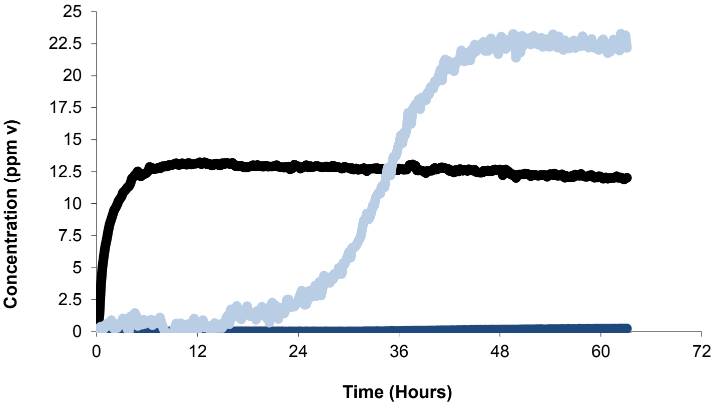

**FIGURE 3** – Silicon containing organics control with single layer of media

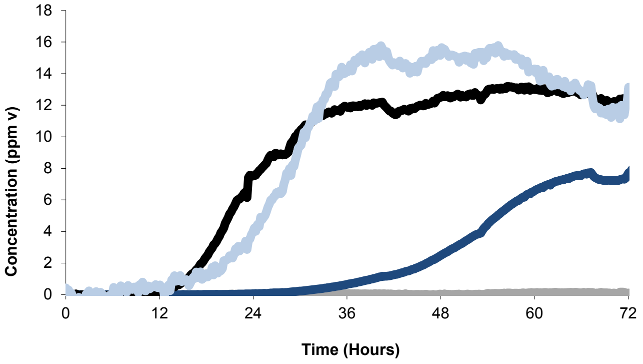

**FIGURE 4** – BSMmax technology effectively controls ammonia and Si-organics with dual layer technology.

## CREATING SUPERIOR PROCESSING ENVIRONMENTS

By developing an in-depth understanding of the chemistry of HMDS breakdown in cleanroom conditions, Donaldson proved that our BSMmax technology provides the solution for cleaner air and more productive work environments. Our proprietary V-bed design combined with BSMmax technology removes both ammonia and siloxanes that can lead to lens hazing. Acid gas filtration and the effective removal of SO2 at low challenge concentrations has already been addressed in SPIE papers from 2005.[4,5]

Available for Donaldson's LITHOGUARD chemical filtration cabinets, point of use filters and replacement filters for other manufacturers' cabinets, BSMmax filters provide tangible benefits of ownership: Maximum protection and longer filter life.

Along with longer filter life and lower maintenance, BSMmax filters are refillable which substantially lowers the cost of ownership and offers environmental benefits.

When it comes to lens hazing, engineers trust Donaldson. We stand behind our filters. With more than 90 years of filtration expertise and the most extensive worldwide network of filtration engineers, manufacturing facilities and technical centers, Donaldson is committed to driving innovation that solves the most complex filtration problems.

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